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DEVELOPMENT OF A CENTRIFUGE MODEL TEST PROGRAM FOR THE STUDY OF LIQUEFACTION

Final Technical Report

by

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SUMMARY

There is a considerable history associated with the use of centrifuge models to achieve realistic data of soil behaviour, including the phenomenon of liquefaction. In this work, the development of an experimental program to establish a database of the behaviour of level saturated sand beds under earthquake shaking is discussed, and a method for the interpretation of the data in terms of conventional design parameters is demonstrated. A review meeting of technical specialists has been held at Waterways Experiment Station to discuss the proposed experimental program and method of analysis, and this has provided strong endorsement of the approach.

LIST OF KEYWORDS

liquefaction
centrifuge
earthquake
model

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1.0   INTRODUCTION

The use of centrifuges to study earthquake phenomena dates to the late 1970s and early 1980s when the first truly dynamic earthquake actuators capable of use in-flight were developed. An area of special interest was the study of liquefaction, a problem in the field which had its first major impact on the engineering community following the 1964 Alaska and Niigata earthquakes, but which reached a new urgency following the failure of the Lower San Fernando Dam in 1971.

Techniques to predict the onset of liquefaction and its consequences have been the subject of extensive research and development, but in the absence of realistic and well-documented field 'truth' data, the verification and validation of these approaches has been problematical. The centrifuge approach permits this obstacle to be overcome, by modeling field conditions in which all conditions (stress, material properties, geometry, loading) are as near identical to the field conditions as possible. Under these conditions, in a well-defined boundary value problem, it becomes practical to test and prove the validity of analytical and numerical approaches to a level sufficient to demonstrate their applicability in standard engineering practice.

This approach has been adopted in a number of specific field cases involving seismic design, including the Pier 400 development in Los Angeles and the seismic design of the large dock walls at Devonport, Plymouth, England for the Trident submarine program. In the Devonport example, centrifuge model tests were used to support the design approach, particularly with regard to the prediction of displacements.

This research contract addresses the first phase in the development of an experimental and analytical research programme in support of the Earthquake Engineering Research Program under the direction of the USAE Waterways Experiment Station, Vicksburg, Mississippi.

In ths report, experience of centrifuge model testing for liquefaction studies is briefly reviewed and recommendations are made concerning the interpretation of model tests to be carried out at WES using the new earthquake actuator.

2.0   CENTRIFUGE MODELING OF EARTHQUAKE INDUCED LIQUEFACTION

It was recognised at an early stage that centrifuge models could provide unique insights into the phenomenon of liquefaction and its effects on engineered structures, Schofield (1980, 1981). Studies of liquefaction induced by river flooding were carried out at Cambridge University in conjunction with WES during the late 1970s. Over the following years shaking tables, developed for use in flight on board geotechnical centrifuges such as the 4 metre beam centrifuge at Cambridge University, England, started to provide the first realistic opportunity to study the propagation of strong ground motion through soil beds, and to observe the deterioration of strength and stiffness of soil as excess pore pressures and large strains developed. A wide variety of earthquake studies have since been conducted using

centrifuge modeling, investigating the performance of many types of engineered structure. Other studies have attempted to study the phenomenon of liquefaction directly, by modeling idealised soil beds of different densities and configuration.

The VELACS (Verification of Liquefaction Analysis by Centrifuge Studies) program in the early 1990s brought together a number of universities in the USA and the UK to study earthquake induced liquefaction of a 'standard' configuration of soil bed, with the twin objects of demonstrating repeatability of technique and of providing data for the validation of numerical analyses. This program was broadly successful in achieving these aims, but the database accumulated during the program is inadequate for the assessment of design approaches for liquefaction prediction (which is the object of the current proposed research studies). In particular, the detailed assessment of factors used in design practice for liquefaction will require a broader and more complete data set than is presently available in the literature, covering a large matrix of tests. The program of work necessary to achieve the current research goals can be seen in Appendix A, the report of the Technical Specialists meeting held at WES to discuss the current program in January 1997.

3.0 MODEL TESTS AT WES

The first earthquake model tests at WES, which were carried out during December 1996 using an earthquake actuator developed by Cambridge University, England, generated encouraging results, showing repeatability between model tests and strong amplification up through the model, as expected. The model container, termed the Equivalent Shear Beam (ESB) container appeared to perform well. The ESB container is built in a laminar form with rubber layers between the laminae allowing for a lateral or shear movement of the container which is intended to reflect the shear stiffness of the enclosed specimen.

A unique feature of the Cambridge ESB container is the provision of shear sheets at each end of the model which lie against the laminae, in contact with the soil specimen. The sheets, which are roughened on the soil side and are anchored to the base of the model container along their length, are intended to react the complimentary shear stresses developed on vertical planes in the specimen as a result of the horizontal shear stresses induced by the base shaking. Without such roughened sheets forming part of the end boundary (stiff in the vertical direction but unable to respond to stresses in the horizontal direction), the distribution of shear stress on horizontal planes in the model is likely to be distorted near the end walls where it would otherwise not be possible to develop the full shear stress on the vertical end wall due to the compressibility of the rubber laminae.

It is concluded that the new, larger ESB container which has been built for the WES earthquake shaker will provide a suitable boundary for the experiments which are envisaged in the main phase of earthquake testing. The characteristics of the new ESB container will require to be established by static and dynamic testing in due course.

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4.0   PROGRAM REVIEW

A meeting of Technical Specialists in the field of earthquake engineering and liquefaction analysis was held in Vicksburg on 3 and 4 January 1997 and provided valuable input to the project through discussion of experimental approaches, instrumentation and interpretation techniques. The experts supported the proposed approach to the evaluation of the K_σ, K_α factors routinely used in liquefaction analysis. The proposed plan for centrifuge and laboratory experiments, described in Appendix A, is now being implemented.

5.0   METHOD OF ANALYSIS OF CENTRIFUGE MODEL TEST DATA

There are a variety of methods for the assessment of the onset of liquefaction and for evaluation of its consequences on the stability of structures such as an earth dam. In this work, where the intent is to use centrifuge model test data of the onset of liquefaction to gain insight into these standard techniques, it is clearly essential to develop an approach which allows the data to be interpreted in prototype terms as if each centrifuge model test constituted a case study, comparable to case studies in the literature used as the basis for design practice, Seed and Harder (1990).

In the Seed and Harder approach, it is recommended that from a calculation of the in-situ static stresses (σ'_o, τ_{hv}), generally by finite elements, and dynamic response analysis to obtain the peak cyclic shear stress ($\tau_{hv,c,max}$), a 'factor of safety against triggering' can be developed by comparing the cyclic stress ratio to cause liquefaction ($CSR_{l,field}$) with the equivalent uniform cyclic stress ratio (CSR_{eq}) where

$$CSR_{l,field} = CSR_l \ C_M \ K_\sigma \ K_\alpha$$

and

$$CSR_{eq} = 0.65 \ \tau_{hv,c,max} / \sigma'_o$$

CSR_l is the cyclic stress ratio to cause liquefaction as a function of the standardised, corrected SPT blowcount $(N_1)_{60}$; C_M is a correction for magnitude (number of cycles), and K_σ and K_α are factors to account for in-situ effective vertical stress and in-situ static shear stress, respectively.

In the field or in a centrifuge model instrumentation can record accelerations and pore pressures at discrete locations throughout a soil bed. The quality of such data and its interpretation, based on examples of data from a centrifuge model test is discussed below. Displacements can also be monitored on the boundaries and certain parameters, such as average shear wave velocity through a zone of soil can be measured using miniature bender elements at discrete times.

From the acceleration time histories there are a variety of methods to compute stress histories. The preferred method is based on an integration of

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F=ma from the soil surface downwards for a soil column of unit dimensions, following Elgamal et al. (1996). For a location midway between two acceleration time histories $\ddot{u}_{i-1}, \ddot{u}_i$, spacing Δz_{i-1}, the shear stress history may be expressed as:

$$\tau_{i-1/2}(t) = \tau_{i-1}(t) + \rho \frac{3\ddot{u}_{i-1} + \ddot{u}_i}{8} \Delta z_{i-1}, \qquad i = 2,3,...$$

This approach may be compared with a computation based on differentiation of the boundary profile in terms of increments of lateral displacement over height which will provide a strain history at different layers in the soil column. Both approaches have deficiencies (eg assumptions over the value of the soil shear modulus), but the opportunity to compare two independent techniques will increase confidence in the predicted values of shear stress at any depth ($\tau_{hv,c}$) determined as a function of time in this way. A further technique which is proposed to provide a rough comparison is simply to use the ground acceleration to predict the stress history at any depth using relations of the type originally proposed by Seed and Idriss (1971) and developed by Ishihara (1996):

$$\frac{\tau_{max}}{\sigma'_v} = \frac{a_{max}}{g} r_d \frac{\sigma_v}{\sigma'_v}$$

where a_{max} is the acceleration at the ground surface and $\tau_{max} = \tau_{hv,c, max}$ is the shear stress on a horizontal plane. The reduction factor r_d may be taken as $r_d = 1 - 0.015\, z$ (z is the depth in metres), Iwasaki et al. (1978).

K_σ is formally defined as the cyclic stress ratio causing 5% double amplitude strain in 20 cycles normalised to the corresponding value of cyclic stress ratio at an effective confining stress of 1 tsf (100 KPa). From Seed and Harder:

$$CSR_{/(\sigma'_o = \sigma'_o)} = CSR_{/(\sigma'_o = 1\ tsf)}\ K_\sigma$$

K_σ reflects observations in laboratory testing that as effective confining pressures are increased, the cyclic stress ratio to trigger 'initial liquefaction' decreases, which may be comparable to the observation that under static loading the tendency for dilation above a critical or characteristic state is also suppressed with increasing effective confining pressures. However, although it is straightforward to derive K_σ from laboratory test data, techniques to derive the parameter from field or centrifuge experience data are less well established.

In the field or in a centrifuge model it is possible to imagine a set of pore pressure transducers and accelerometers at different elevations in a soil column. At each location, a time history of excess pore pressure development will be recorded under the dynamic excitation. Ideally, for direct comparison with K_σ as derived from laboratory tests, the dynamic excitation would take the form of near-uniform cycles of loading, generating stress histories which are readily interpreted in numbers of equivalent uniform cycles.

Excess pore pressures generated at different elevations will be under slightly different amplitudes of cyclic stress history, due to amplification up the column, but will reflect the same cycles of loading. In level ground, excess pore pressures will approach the initial overburden stress most rapidly from the surface downwards.

Figure 1 shows data of ground response captured from a centrifuge earthquake test of a saturated sand bed, in the main body of a larger embankment model, Steedman (1986). Time histories of excess pore pressure (PPT 2628 and PPT 2255) were recorded at different depths, along with horizontal accelerations at the top and bottom of the bed. The base input motion, measured on the specimen container itself is shown by ACC 3441. The 'time' axis is given in data points. The data point spacing in the model was 150 microseconds, which is equivalent to 12 milliseconds in the field (prototype). The shaking can be seen to comprise ten strong cycles over around 8 seconds, with one or two minor cycles towards the end of the record.

Using this acceleration data, time histories of shear stress at different depths can be estimated using either the Seed and Idriss approach or the Elgamal method (described above) and these are shown in Figure 2. From these records the peak cyclic stress ratio can be easily found, and this is also given in the figure. However, as the Seed and Idriss method relies solely on one acceleration record (ground surface), a comparison was also made between the peak cyclic stress ratio based on the unprocessed (raw) data record and a 'smoothed' record based on a simple function (0.25 times the previous data point plus 0.5 times the current data point plus 0.25 times the next data point) designed to remove spurious high frequencies which may give a distorted view of the peak stress ratio. Comparisons between the CSR computed using the smoothed data and the Elgamal computation (which is based on a weighted sum of two acceleration records) are encouraging.

This example demonstrates that the method can be used with centrifuge model test data, but as a further check the final values may be compared with separate computations, using numerical methods.

Using the in-situ effective overburden pressure at each pore pressure transducer, it is straightforward to compute the development of excess pore pressure as a percentage of the overburden, Figure 3. It is conventional to base the computation of K_σ on the number of equivalent cycles to reach initial liquefaction. In this case, as the excess pore pressure does not reach 100% of the initial effective overburden pressure, an alternative approach is to compare the number of cycles to reach a lesser percentage, for example 60% of σ_{vo}'. Using the trend line through the pore pressure data in Figure 3 and comparing the time at which the residual pore pressure reaches 60% of σ_{vo}' with the original time histories of the cycles of input motion (Figure 1), the number of equivalent uniform cycles of shaking for a given cyclic stress ratio can be computed, giving results as shown in Figure 4.
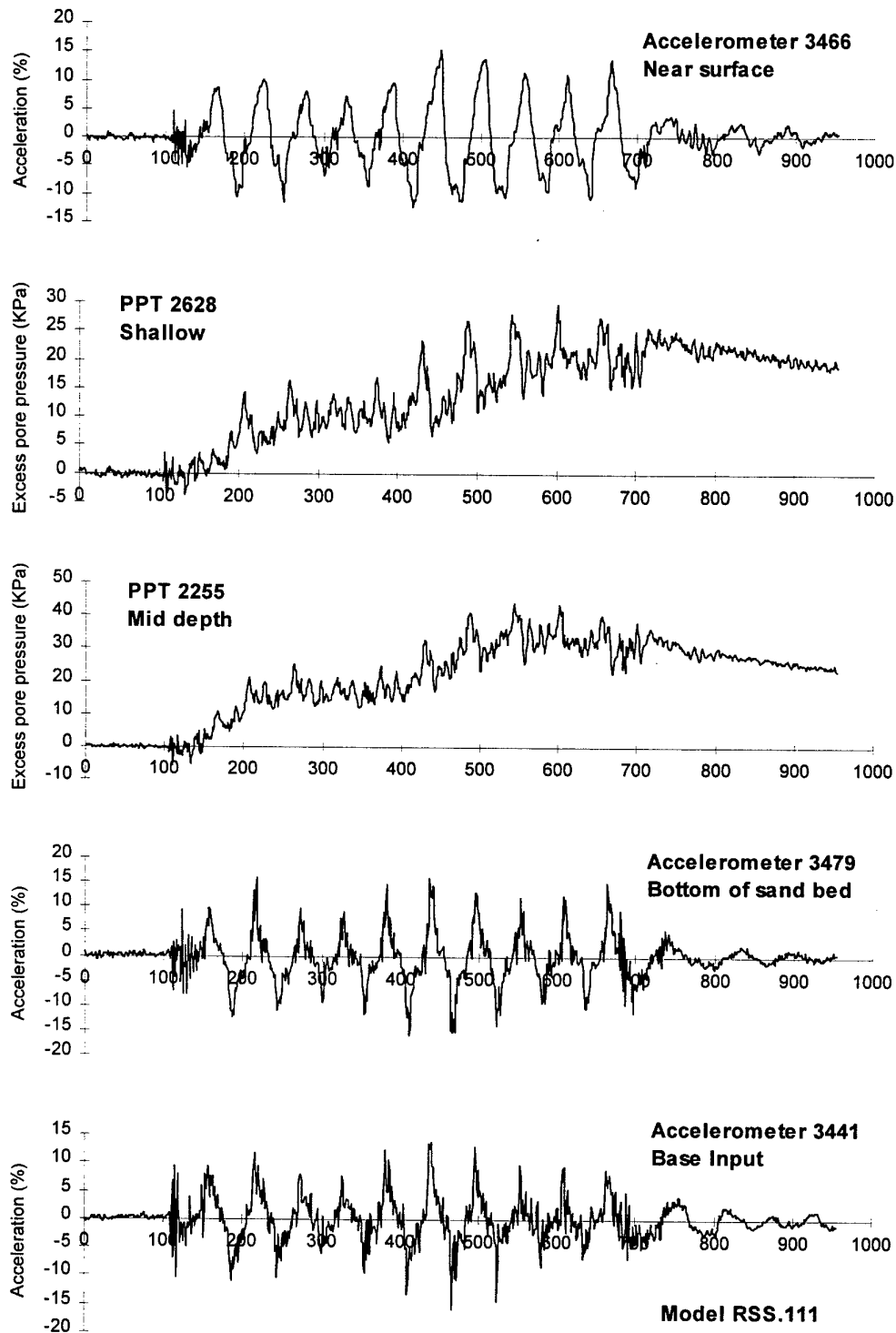
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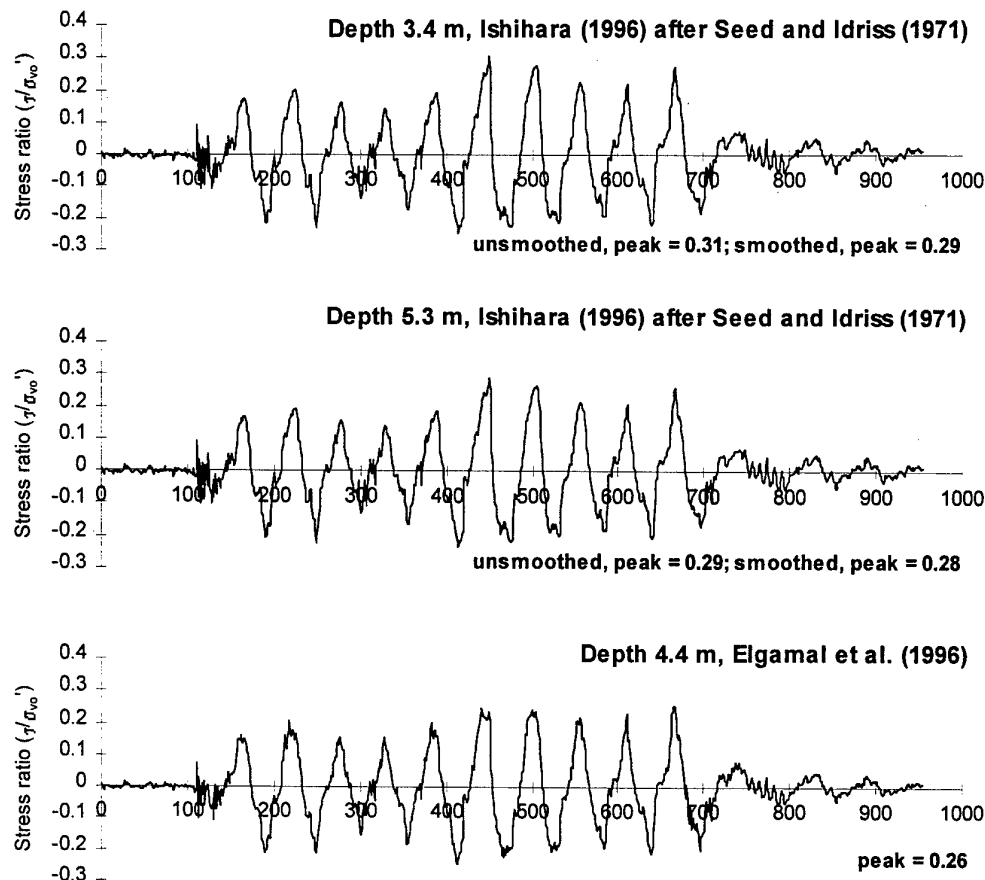Figure 1: Data from centrifuge model test showing ground response

Figure 2: Stress ratio calculated at different depths

In Figure 4, curves of constant effective overburden pressure run through the data points representing (in this case) 60% of the initial effective overburden pressure. Other earthquakes in the series of different amplitudes would provide other data points on the same curves, as each curve relates to a specific transducer depth.

In this example data, neither of the two pore pressure transducers were located at sufficient depth to have an initial overburden pressure equal to 1 tsf (100 KPa). However, this analysis demonstrates the approach by which such curves can be established and as the relationship between these curves will be a function of K_σ, and with a full column of transducers in a deeper sand bed it will be practical to deduce K_σ from centrifuge model earthquake tests of this kind.
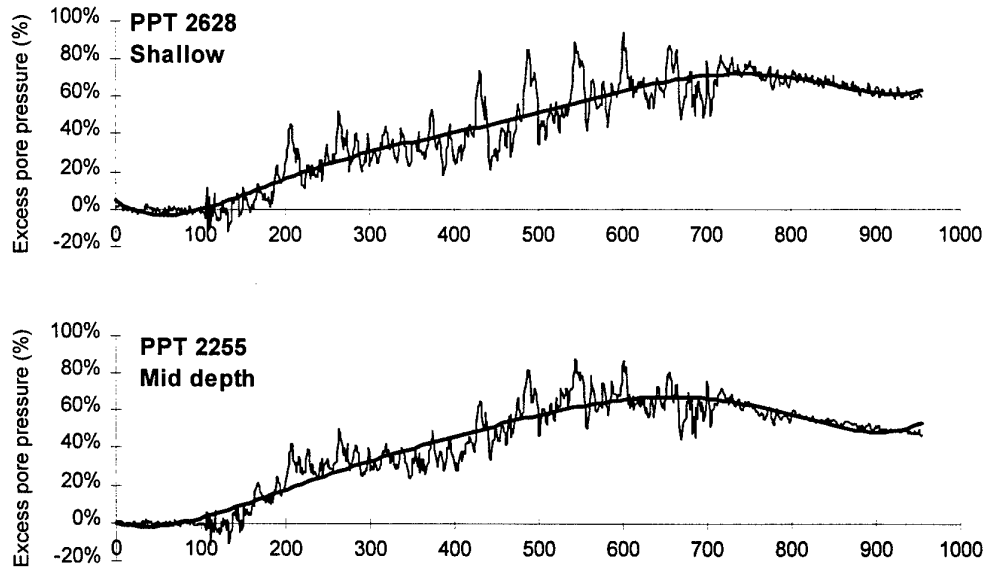
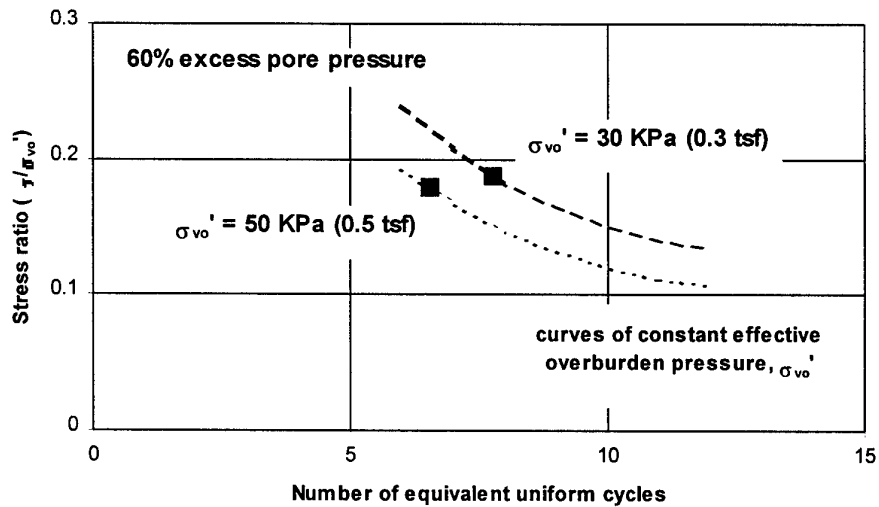Figure 3: Estimation of residual pore pressure at different depths

Figure 4: Development of curves of excess pore pressure as a function of number of cycles

6.0   CONCLUSIONS

A method for the interpretation of field or centrifuge model test data for use in the determination of K_σ has been demonstrated using sample test data from the response of a centrifuge model test of a saturated sand embankment.

The method has been reviewed and approved by an external review panel of Technical Specialists, providing confidence that the series of centrifuge earthquake model tests on deep level saturated sand beds now being undertaken will provide considerable insight into the factors such as K_σ which are commonly used in the assessment of liquefaction potential in design practice.

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APPENDIX A

BEHAVIOR OF LIQUEFYING SOILS

Technical Specialists Meeting
3-4 January 1997

REPORT OF MEETING

Attendees:

R H Ledbetter
Dr R S Steedman
Professor W D L Finn
Professor R Dobry
Professor I Idriss
Dr G Castro

1.   Corps Civil Works Earthquake Engineering Research Program

The meeting opened with a briefing on the EQEN program, purpose "to improve our ability to predict the performance of a dam under seismic loads, and to improve our ability to design and construct cost-effective remediation". The importance of this program, the only Federally funded seismic safety program for dams, was emphasised. It is intended that the program will have a major impact on the need for, and scope of remediation of dams in seismic areas in the US.

Four main areas are being addressed:

a.   earthquake ground motions;
b.   site characterisation;
c.   performance assessment by numerical and physical models;
d.   remediation.

The work unit on Behavior of Liquefying soils falls under c., performance assessment. Other work units on which centrifuge modeling is planned to be used were briefly described: Newmark sliding block, Failure mechanisms, Remediated soils earthquake behavior, and Soil stresses and state.

2.   WES Civil Engineering Research Centrifuge

The origin and purpose of the BAA, and the current status of the centrifuge center at WES was presented. It was noted that the Army requirement to achieve a capability of modeling large prototype behavior had driven the definition of the design operating envelope, and in particular that the

requirement to carry 2 tonnes of payload on a flat platform at 350g had dominated the mechanical and structural design of the machine.

Commissioning of the centrifuge commenced in early 1996, and the continuing process of check-out tests and the progressive extension of the operating envelope with detailed instrumentation of the machine, buildings and surrounding area was briefly described.

Transfer of technology in centrifuge modeling has involved developing a wide range of appurtenances and experience, with demonstration tests including ice models, groundwater experiments, environmental models, slope stability and earthquake studies have already been carried out. Future planned work includes pavement models, studies of beach formation, and blast experiments.

The group toured the facility.

3.   Behavior of Liquefying Soils Research Project

Based on assessment of the current state of practice in the seismic evaluation of earth dams, the detailed needs in liquefaction research were summarised as follows:

a.   complete shear stress-strain response curves;
b.   strains within a problem soil mass;
c.   effects of soil thickness, permeability, and boundaries;
d.   influence of adjacent soil materials;
e.   dissipation and movement of excess residual pore pressure during and after earthquakes;
f.   redistribution of stresses as a soil is losing strength;
g.   interaction of remediation materials and adjacent soil;
h.   dynamic response of remediation materials and zones;
i.   improved K_σ and K_α factors for evaluation of remediation and for first estimate of liquefaction potential;
j.   effects of strong aftershocks.

The objectives of the Work Unit had therefore been developed as follows:

A.   define the behavior of liquefying soils and affects on dam behavior;
B.   improve K_σ and K_α factors;
C.   define the complete stress-strain curve and simplified methods for obtaining it;
D.   expand and enhance the earthquake case history data;
E.   provide progressive results for immediate use by the Corps.

The approach would include use of centrifuge tests to capture equivalent prototype behavior under known laboratory-quality conditions, the use of laboratory tests and the use of analytical procedures to bridge centrifuge and prototype conditions and to explore the mechanisms of behavior. This was described in detail by reference to an example test plan for the evaluation of K_σ which would include the construction of a number of 'test sites' with a 24 ft thick layer of saturated liquefiable sand overlain by a varying depth of denser

overburden of lower permeability. Measurements of dynamic response and in-situ properties and conditions would then enable K_σ to be evaluated directly with increasing overburden pressure and as a function of density, soil type and at different levels of excess pore pressure development.

Extensive discussion of the proposed approach confirmed the usefulness of the centrifuge as a tool to investigate the K_σ and K_α factors and emphasised the importance also of demonstrating the consequences of liquefaction or, in the extreme, flow-failure. Reference was made to classic examples of major dam failures and to experimental centrifuge work which had exhibited large scale movements following high excess pore pressure generation. It was agreed that ultimately it would be desirable to show large scale movements in a centrifuge model and that this could form part of the third phase of the work unit, on dam response.

The third phase is planned to follow the current phase of work, addressing K_σ (which is expected to last around one year) and a second phase addressing K_α.

It was agreed that work in the first year should be sufficiently self-contained to show immediate, tangible benefits for practice.

4. <u>Discussion</u>

4.1 <u>Selection and interpretation of input shaking motion</u>

Typical time histories of shaking motion were reviewed and discussed. Techniques to identify and filter out electronic noise such as cross-correlation of data captured before the earthquake may be advantageous in the processing of the raw records. Filtering of records was considered acceptable, provided that the selection of the filter criteria could be adequately justified. It was noted that vibrational energy at up to 10 - 20 Hz (prototype values) may be important in influencing the soil response and that this should be taken into account in any filtering process.

Examination of recent records from models in the Equivalent Shear Beam (ESB) container indicate that the container may be driving the model response, providing a strain controlled 'simple shear' system. If this is proven, it could be useful for the present test purpose, where a series of cycles of motion of constant amplitude are required at any elevation, comparable to the standard approach of using strain controlled cyclic or monotonic element tests.

The different operation of the ESB model boundary (which collects and reacts the shear forces at the ends of the model) from alternative containers constructed with nominally frictionless laminae was considered to be a benefit in minimising effects caused by the horizontal inertia of the container walls being transferred into the soil.

The technique of System Identification was recommended to analyse the soil response. This approach would use accelerometer data to derive shear

stress history at different elevations (by summation of F=ma over depth) for comparison with strain (based on displacement) histories derived by double integration and then subtraction of two adjacent levels. Confirmation of the displacement time histories could be achieved by direct measurement of the lateral movement of the laminae on the ESB container. Concerns were raised over the validity of subtracting displacement histories, particularly at high levels of excess pore pressure. It was considered that the direct measurement of lateral displacement may provide a more reliable indicator of lateral strains, particularly if the ESB container could be demonstrated to be driving the response of the specimen.

The importance of close vertical spacing of accelerometers was stressed, and five levels of instrumentation within the liquefying layer was considered adequate for the test purpose. Accelerometers should be placed along selected horizontal planes in certain models to check one-dimensionality of response. Accelerometers may also be used on the laminae of the container to compare with the direct lateral displacement measurements.

4.2 Development of pore pressure curves and calculation of K_σ

It was considered that the development of pore pressure curves could be based on comparisons 'cross-model' at a common elevation in the liquefying layer and also 'within-model' by comparison of two different elevations, to generate data points at different percentages of excess pore pressure generation, such as 50, 60, 80 and ideally 100%. The same percentages would be adopted for interpretation of the laboratory tests results. It was accepted that interpolation would be required to generate families of curves. The comparison between calculations of K_σ at different percentages of excess pore pressure would itself be an important contribution from the research.

4.3 Construction techniques and effects on K_σ

It was considered that the method of sample preparation can have a significant influence on the cyclic resistance (and might have an effect on K_σ) and hence for comparison purposes the method of preparation in the laboratory and in the centrifuge models should be as similar as possible. In the lab tests it was agreed that several techniques should be used, including dry pluviation (similar to the centrifuge) and moist tamping. Hollow cylinder torsional shear tests should be used in conjunction with cyclic triaxial tests, using isotropic consolidation.

4.4 Density measurements

Measurements of density can be made by examination of block samples using non-expanding setting gel. It may be necessary to construct models purely for the measurement of consolidation settlement, which would be accelerated to the test gravity and then stopped and dissected without shaking. Pore pressure transducers may provide some information on ground

movements through changes in static readings; settlement measurements, ideally at different depths, were considered to be essential.

4.5 Measurement of in-situ properties and conditions

Ideally a cone test would be available in flight to be deployed before and after each earthquake. However, if this proved impractical, it was considered that a separate model (as for measurement of consolidation) could be used to carry out cone penetration tests of the samples at the appropriate test gravity level. Similarly, a cone test could be carried out after the earthquake, probably by stopping and restarting the centrifuge.

It was recommended that the use of bender elements could be pursued as an approach to measure shear wave velocity at different stages through the model test, although interpretation of such data can be problematical. Compression wave velocities were considered to provide a good indicator of saturation.

Shear modulus degradation curves will need to be developed to facilitate analysis of the model tests.

4.6 Undisturbed sampling

Recommended methods of extracting block samples or cylindrical samples include the use of non-expanding setting gel followed by coring and the use of piston sampling using a fixed tripod (to measure any volume change). Block samples could be studied using X-rays or used for other measurements, such as water content and hence void ratio. It was considered that marker layers would help visual examination of the models after the earthquake. Other ideas for extracting samples included burying sample tubes in the model during construction and which would be assembled in sections as the model was poured. Alternative techniques could be used simultaneously to provide confidence in the technique.

4.7 Load tests after liquefaction to measure undrained strength

Options which were discussed included vane tests, bearing tests, pile loading or lateral loading of the ESB container. It was considered that such tests could be difficult to interpret and it was agreed that although ideas should continue to be explored the concept may be impractical and it should remain a low priority at present.

4.8 Effects of prior low-level seismic shaking and aftershocks

Discussion centred around the significance of the prior history of low-level vibration in soil deposits. It was considered that the topic should be reviewed at a future date for possible inclusion in future test plans. Studies to explore this area might involve repeating similar work carried out on shake tables which has looked at the effects of low level shaking on liquefaction resistance.

4.9   <u>Effects of stress history</u>

The effect of overconsolidation was considered to be an important topic and it was recommended that this aspect should be brought into the model test program at a future date once the early data has been generated and analysed. In the first phase of tests, however, models should not be accelerated beyond their test g level. It was noted that studies, for example by Jamilkowski, may provide useful background information.

4.10   <u>Effects of fluidisation (prior liquefaction)</u>

It was recognised that fluidisation could erase prior history in the soil specimen but it was considered that this was probably impractical as a static process during model construction. The effects on K_σ of the history of prior liquefaction should be considered for study in future phases by the firing of successive earthquakes on the same model. It was noted that this approach may lose some information on the consequences of the first shake, but this could be partly addressed by using information from earlier duplicate models as an indicator of the likely conditions prior to the second earthquake. As with stress history effects, it was considered that the study of this effect should be reviewed following the development of the initial model test data-base.

4.11   <u>Model test matrix</u>

It was considered that two relative densities would be adequate for the liquefying layer, with a minimum of around 40%, and an upper value of 65%. It was recommended that the range of overburden depths should be reviewed and optimised depending on the expected distribution of data.

It was suggested that percent compaction may be useful as a parameter (equivalent percent compaction for sands) to assist in the comparison with the silty sand models planned in future. (Cone values may also provide information in this area although some concern was expressed over the necessary corrections that would need to be applied.)

It was recommended that the first year's work should concentrate solely on Nevada sand and alternative sands or silts should be postponed until the first data-set was completed. (The proposed silty sand was considered to be the preferred choice for a second soil, rather than a further clean sand. However, consideration would be given to switching to a second clean sand if early laboratory test data showed a low sensitivity of K_σ to overburden pressure.)

Future work may consider studies on an SW sand.

The upper (non-liquefying) layer should be selected such as to have a permeability of around 1/10 of the liquefying layer, probably by the inclusion of some silt. It was considered important that the upper layer should not form an impermeable blanket. Concern was raised over decoupling of the upper layer through an interface fluid layer but it was considered that this would not have a significant effect on the calculation of K_σ in the early stages of pore

pressure generation. This would be reviewed if large scale decoupling became apparent.

It was recommended that for the first phase all saturated models should use a pore fluid with the correctly scaled viscosity; water saturated models were not thought to be necessary or desirable as the rapid dissipation and potential redistribution of pore pressure may influence the results. The option of using water should be reviewed at a later stage.

4.12   Parallel tests

It was considered that a parallel test would be desirable in a later stage of the project, to provide additional confidence in data processing and verification of the final conclusions. Such a test would generally make use of the test equipment available at the selected institution but it would be necessary for the work to be specified and observed by the original model makers. The concept of parallel tests would be reviewed during the second phase of the project.

5.   Future meetings

The next Technical Specialists meeting was scheduled for 29 and 30 September 1997, with the option of an earlier date on 29, 30 August 1997 depending on the availability of individuals. This would be confirmed in around two months time.

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1 March 1997